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early days, would have taken different directions. But the following out of these subjects is not within the province of a geological paper.

NOTE.—Since the above paper was written I have been favored by the courtesy of Mr. O. Guthrie, of Chicago, with a copy of the Report of the Committee on the Drainage of Chicago, and a letter containing some further interesting details upon the subject. From these data I learn that the low ridge behind Chicago, mentioned in the above paper, has a breadth of only five miles, and that a scheme is on foot for cutting a canal or a channel through it to the Des Plaines river in order to carry away the sewage of the city entirely from L. Michigan, and avoid the contamination of the water-supply, whose purity is now seriously endangered by the flow of drainage into the lake not far from the crib, during floods in the Des Plaines river.

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THE ARTHROPOD EYE.

BY J. S. KINGSLEY, SC.D.

THE year 1886 has already seen several important studies upon the eyes of Arthropods, some of which have materially altered our conception of the organ and of compound vision. Of these studies by far the most important are those detailed in Dr. William Patten's "Eyes of Mollusks and Arthropods" (Mitth. zool. Stat. Neapel, VI, pp. 542–756. pls. XXVIII–XXXII, 1886). The paper is far too long for complete abstract here, but some of the more important points relative to the compound eye may be useful in supplementing the statements in the manuals of comparative anatomy. Incidentally it may be remarked that the matter pertaining to the eyes of mollusks is equally valuable.

As described in our hand-books, our knowledge of the eyes of Crustacea, spiders and insects is based on Grenacher's classic "Sehorgan der Arthropoden" (1879), and no one (Graber excepted) has ventured to criticise his results. Not so Dr. Patten. He has shown that Grenacher is wrong in many fundamental points, and that his conception of these organs is in some respects so erroneous as to be all but worthless. The writer, in passing, may remark that he has had occasion, in studies in a somewhat different direction, to verify many of Patten's statements, and so far as he has gone he can confirm them. The figure of one of the elements of the eye of the shrimp, illustrating this article, is drawn from his own preparations, but in all essential features it agrees well with similar figures of the eyes of other Crustacea given by Patten. The ramifications of the distal end of the optic nerve were not seen and have been inserted from Patten.

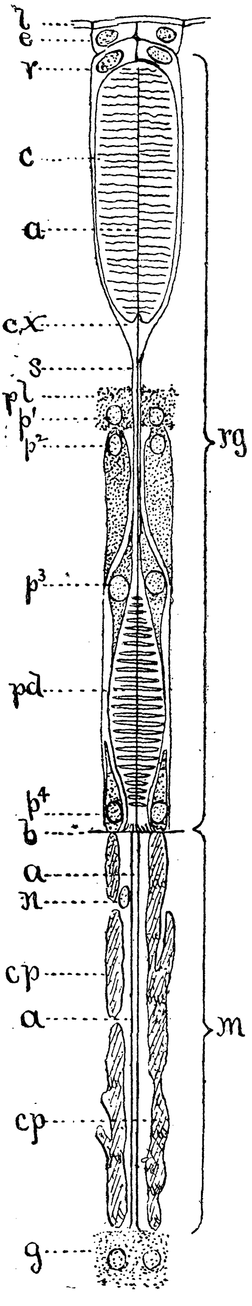

FIG. 1.—Diagram of a single element (ommatidium) of the eye of a shrimp (Crangon). *a*, axial nerve fiber and its distal terminations; *b*, base of pedicel; *c*, crystalline cone; *cp*, connective-tissue pigment; *cx*, calyx formed from retinophoræ; *e*, epidermis (hypodermis); *g*, ganglionic layer; *l*, corneal lens; *m*, mesoblastic portion of eye; *n*, nucleus of connective tissue; *p 1, 2, 3, 4*, pigment cells and nuclei; *pd*, pedicel; *pl*, external pigment layer; *r*, retinophora; *rg*, portion of eye derived from retinogen. The termination of the axial nerve in the crystalline cone is supplied from Patten, the rest is drawn from actual sections.

On the external surface of the compound eye is the facetted chitinous cornea, each facet of which is regarded as a lens (*l*). Immediately beneath this comes a layer of epidermal (hypodermal) cells, *e*, the existence of which was utterly ignored by Grenacher. These secrete the cornea. Next in order are some cells (retinophoræ, *r*) which are rather complex in their structure and relations. There are four of these to each facet, and they lie exactly below the corresponding epidermal cells. The nuclei are placed in the outer ends, and thence the protoplasm runs backwards to the basal limit of the retinal portion of the eye marked by the line at *b* in the figure. A short distance from the surface they contract to form a slender stalk or style (*s*), and these enlarge, in a graceful manner, to form a pedicel (*p*).

Between the nucleated portion of the retinophoræ and the style are some features existing in the shrimp and some other forms, but not in all. This part of the cells in the form figured is extremely thin, and the space between the four cells which make up one optic element, or 'ommatidium,' is occupied by a transparent body, the crystalline cone (*c*). Below the cone the retinophoræ are slightly enlarged. It is, however, with regard to the pedicel that one of Dr. Patten's most important discoveries were made. According to Grenacher, this part (his rhabdom) is secreted by the surrounding pigment cells, but Dr. Patten claims that it is in reality but the coalesced proximal ends of the four retinophoræ.

Surrounding the portions of the eye already described are a varying number of pigment cells (about sixteen in Crangon); around the nucleus these are large, but at either extremity they thin out into fine threads or rods which, according to Dr. Patten, extend, like the retinophoræ, from the epidermis to the basal membrane. I have not been able to trace these extensions except in part, and hence have omitted them in the drawing. It seems probable that a variation occurs in these rods with the species, though Dr. Patten (p. 637) is inclined to the contrary view.

At the base of the ommatidium a large nerve fiber (*a*) is seen coming from the deeper portion to the base of the pedicel. According to Patten this divides just before reaching the basal membrane, and gives off branches to each of the cells (pigment cells, retinophoræ) composing the optic element. And farther, branches go to adjacent elements so that each ommatidium receives its nerve supply from four different main bundles. The arrangement of these is very complex, and need not be described. The fiber, however, which penetrates the axis of the pedicel seems of more importance to a conception of the phenomenon of vision, and hence a word is necessary. It runs through the pedicel and style and penetrates the crystalline cone, where it gives off fine fibrillæ which radiate in every direction towards the outer wall. These are points which seem to have escaped all previous observers. The writer has traced the axial fiber into the cone, but has not seen the other details.

Of the various theories and conclusions advanced by Mr. Patten as results of his studies, we have room to mention but three: First, the existence of the radiating fibers in the crystalline cone (or in the retinophoræ when the cone is absent) shows that at that part of the eye the image is formed, and the suggestion at once follows that by the depth of this layer of fibers there is adequate compensation for lack of adjustment, for no matter where the image produced by the lens may fall, it will fall upon fibers of the nerves. So too these observations tend to throw discredit on the "mosaic" theory of the vision of the compound eye, a theory that already was too open to objection to be implicitly accepted. Lastly, a point to be referred to again, Dr. Patten comes to the conclusion that the compound eye can not be regarded as evolved by a coalescence of ocelli.

A second important paper on the Arthropod eye has already been mentioned in the pages of this magazine, but its connection with the subject in hand will excuse its being brought up again. Though several authors have mentioned facts in the development of the arthropod eye—some, like Bobretzky, giving details of importance—Mr. Locy was the first to indicate the most important feature in the process. In his paper entitled "Observations on the development of *Agelena nævia*" (Bulletin Mus. Comp. Zool., XII, pp. 63–103, 12 pls., 1886), he shows that in an early stage the eyes appear as local thickenings of the epidermis followed by an invagination of these thickened portions which thus come to lie beneath the surface. The pouches thus formed, one for each eye, are then cut off from the parent layer, and we have now to deal with three layers. From the outer (epidermal) arises the cuticle, cuticular lens and vitreous body of the adult; from the middle arises the retinal elements of the adult (exactly how was not clearly determined) while the fate of the inner layer was not traced. Locy points out that as a result of this mode of development, one supposed difference between the eyes of arthopods and those of vertebrates disappears, and the rays of light traverse the retinal elements of the one group in exactly the same direction with regard to their origin as they do in the other.

Sedgwick (Quart. Jour. Micros. Sci., XXV, 1886) was the first to point out that the eye in Peripatus was developed from an invagination. The outer wall of this sac is described as forming the epithelium outside the lens of the adult eye, while the inner wall joins the cerebrum and gives rise to the retina. Hence, says Sedgwick, the eye of Peripatus is a cerebral eye.

Kennel has also studied the development of the eye in the same genus (Entwicklungsgeschichte von Peripatus, II Theil. Arb. z. z. Inst. Würzburg, VIII, pp. 1–93, pls. 6, 1886), and gives (pp. 31–33) further details. He too recognizes the invagination, which becomes cut off from the parent layer, but says that its inner wall has no close connection with the rudimentary brain, but that the nervous connection with that organ is secondary.

This is the most important difference from Sedgwick's very brief account. Certainly Kennel's figures do not support the view that we have here to do with a 'cerebral eye;' but it must be borne in mind that he and Sedgwick are studying different species.

Next comes a preliminary communication on the development of the ocelli of Hymenoptera, by Carrière (Zoologischer Anzeiger, IX, pp. 496–500, 1886). Here the optic epidermis becomes at first two cells deep, and then these become obliquely invaginated, both layers retaining their "normal" position. The outer layer forms the lens-generating cells, the inner the retina-forming ones. The cells which are not invaginated become elongate and, together with the invaginated lens-building cells, form the corneal lens. These cells never lose their connection with the epidermis while those of the retina do. The cavity of invagination does not close up but is occupied by the corneal lens. Thus runs Carrière's account; but it is very difficult to understand it, as it is not illustrated.

I have now a few observations of my own to record. In Crangon the eyes arise from invaginated pits, and here as in the spider, Agelena, we have three layers to deal with. These are the unmodified epidermal layer and the two walls of the invaginated pouch. The one of these latter which comes to be the more external I have termed the retinogen because from it arises the retinal elements; the other, from analogous reasons, is the gangliogen. So far the account is closely similar to that of Locy as outlined above. I have, however, been able to trace the development of all the parts of the adult eye, which in outline is as follows. The cells of the gangliogen elongate and each divides, giving rise to a row or series of cells which grow upwards toward the mathematical center of the eye and produce the chain of ganglia and nerve fibers which lie in the stalk of the adult eye. In a somewhat similar way the cells of the retinogen elongate and divide transversely, each giving origin to five cells which also lie in a radius of the eye. Of these the outer forms the retinophora of the figure above while the others develop into the pigment cells. All of the structures embraced in the bracket *rg* in the figure are hence derived from the retinogen, while from *g* inward until connection is made with the cerebral portions all is of gangliogenous origin; the space between the two indicates the position of the cavity of the invaginated pouch. In the adult it is filled with pigment, connective-tissue and nerve fibers. The latter grow out from the ganglion, the others are of mesoblastic origin, and force their way into the cavity at about the time when the cells of its walls begin to elongate. The crystalline cone is plainly formed by the walls of the retinophora and these same cells can also be seen to elongate and unite to form the pedicel, thus clearly demonstrating the truth of Patten's position and the error in Grenacher's conception of the rhabdom. I hope soon to publish a detailed account of my results with figures which will make clear all the points indicated above.

This development of the compound eye from a single invaginated pit shows conclusively that this organ could not have arisen from a confluence of ocelli, but must have had its origin from the division of a simple eye in some respects like that of a spider. Farther, the close correspondence observable in the development of the eye of a spider and that of a crustacean, as outlined above, and the difference of both from that of Peripatus and the ocelli of Hexapods, go far toward sustaining the position I took last year (Inter-relationships of Arthropods, this journal, XIX, pp. 560–567; and Embryology of Limulus, Quart. Jour. Micros. Sci., XXV, pp. 521–576) that the group Tracheata is not a natural one, and that the spiders are far more closely related to the Crustacea than they are to the Hexapods, with which they are usually associated.

At the same time the structure of the eye in the adult Peripatus does not at least conflict with another point I suggested in the paper in the AMERICAN NATURALIST just quoted, *i. e.*, that Peripatus, in spite of its tracheæ, is not an Arthropod at all. To be sure it arises by an invagination, but so does that of cephalopods and, in a modified way, those of vertebrates. We know almost nothing of the development of the eyes of other groups, but the almost perfect similarity shown between the eye of the adult Peripatus as figured by Balfour and that of the syllid worm Autolytus as it is seen in my own preparations—a similarity extending to almost every detail—renders it a not very rash step to predict that invagination will be found to play a part in the development of the annelid eye as well.